The Future of Luminaires

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The Mission of Lighting Solution Providers

Bring Products to Market Based on 2 Major Criteria

- *Meeting the Illumination Performance Requirements*

- *Meeting the Economic Performance Requirements*

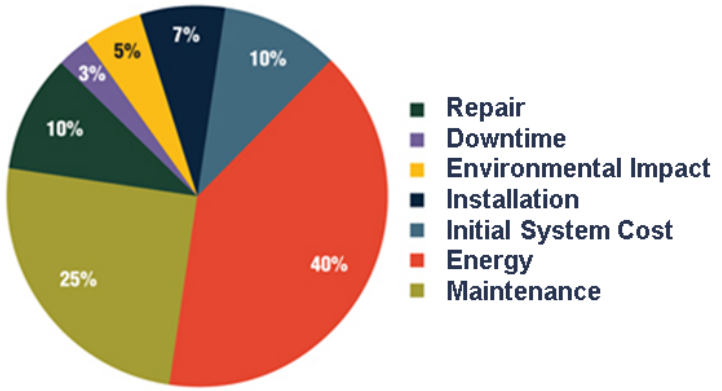
Life-Cycle Cost Analysis Justifies Adoption

Goal:

Maintained Illumination Performance

Maintained Economic Performance

Throughout the Life of the Application



Note: Proportions are Arbitrary

Does LED technology provide the opportunity to provide higher value than traditional sources???

- Energy Consumption
- Service Life
- Heat (i.e. HVAC load, etc.)
- Color Quality
- High Luminous Flux Options
- Precise Optical Control
- Dimming / Controllability

Outdoor Area Lighting 2007

Outdoor Area Lighting 2007

HPS		LED
300W	Total System Wattage	141W
20,520	Average Delivered Lumens	8,040(61% less Light)
68	Luminaire Efficacy (Lumens/Watt)	57
1.96fc	Maintained Average Footcandles	1.01fc
0.30fc	Maintained Minimum Footcandle	0.30fc
-	Energy Savings	53%

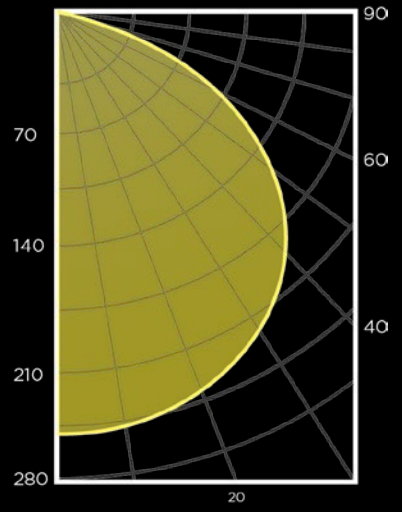
The Value of Lighting Design

Sometimes the Lighting Design Process Can be Simple

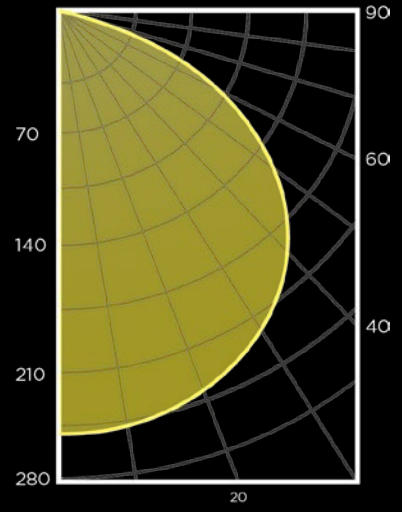
Example:
Direct Replacement LED Products

- Take the most popular downlight configuration…
- **Replicate** the aesthetics, output, color quality and light distribution…
- Improve the efficacy and eliminate all routine maintenance (i.e. relamping)

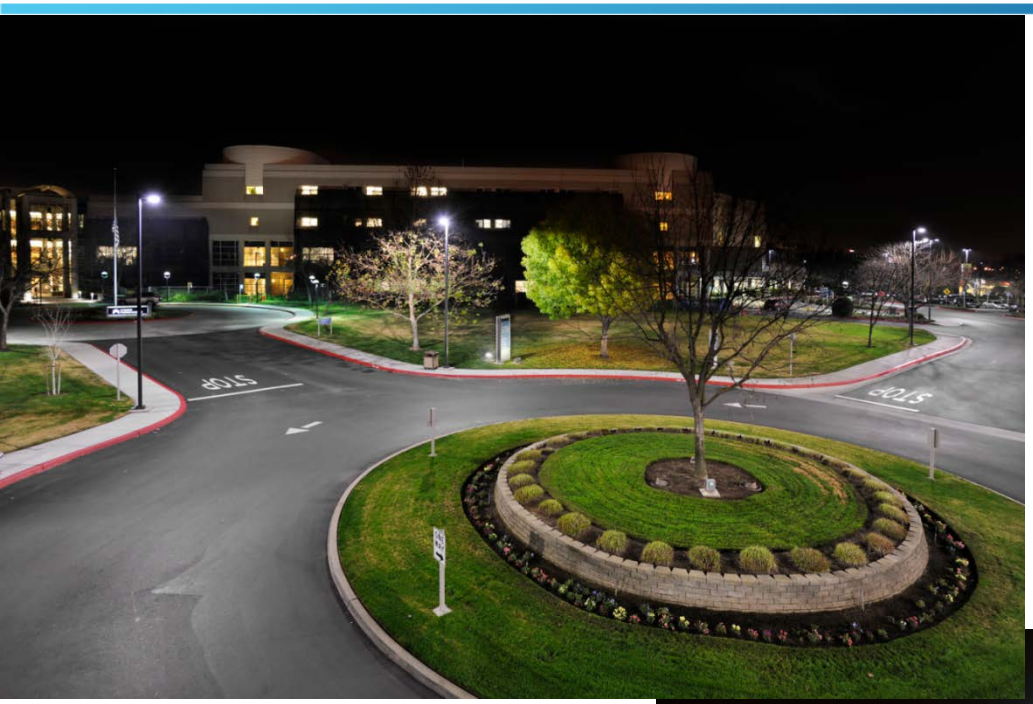
65W BR30 FL
CRI = 100



<10W
CRI = 92



2008 Street and Roadway Lighting Products



2008 Street and Roadway Lighting Customer Requirements

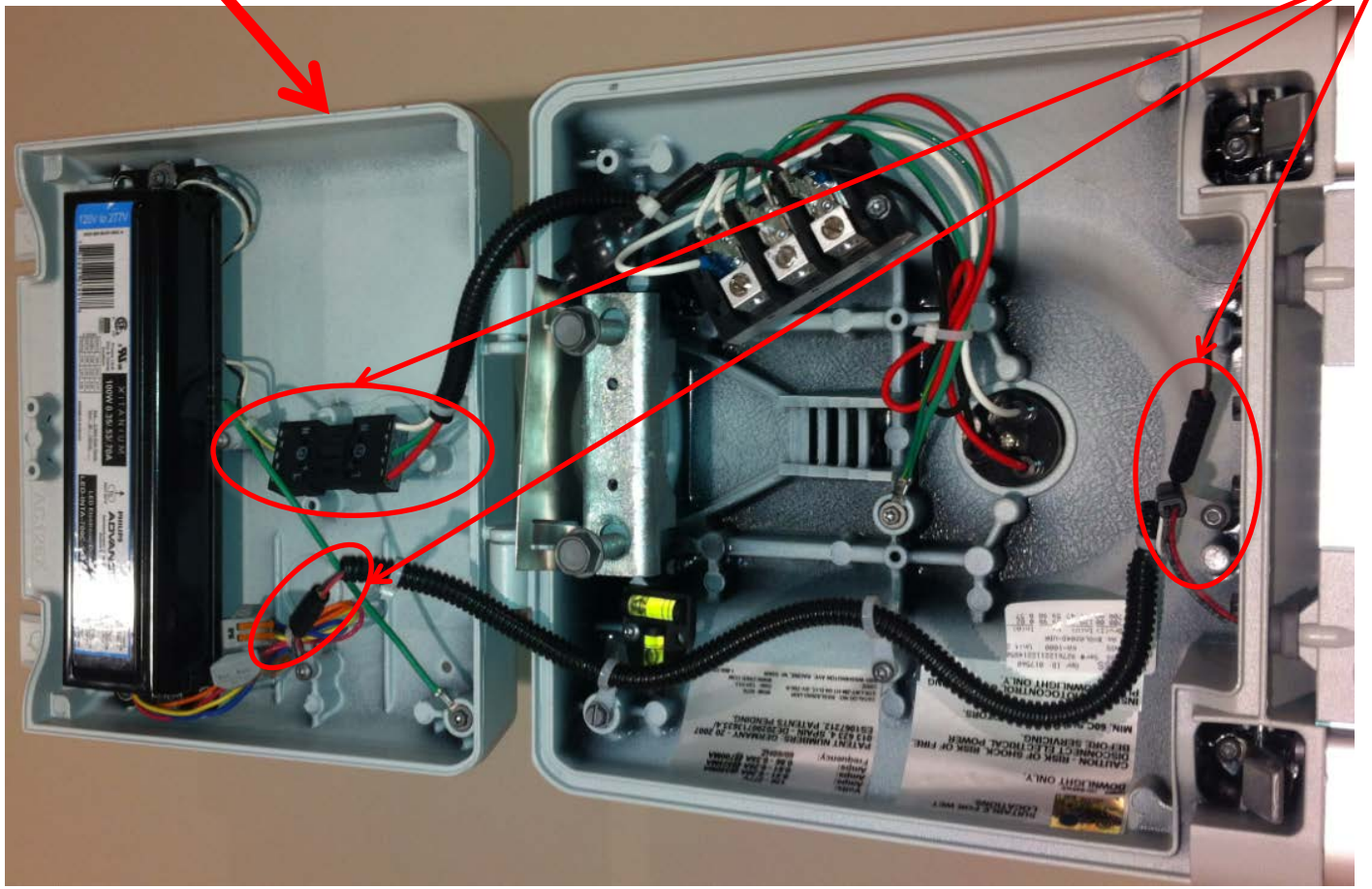
Consumer (User) Confidence Was Low
Risk Aversion was High (i.e. Prove it Works)

- Installs the Same as the Incumbent Light Source Technology Solutions
- Field Serviceable
  - Light Source (circuit boards and optics)
  - Power Supply (sometimes called the “Weak Link”)
  - Upgradeable or “Future Proof” (no throwaways)
- Make the Product Look Like the Traditional Cobra Heads
- Make Sure it Installs/Wires Exactly the Same
- Make All the Same Options Available
  - Twist Lock Photo Control
  - Tool-less Access “Power Door”
  - Etc…
- Typically 3 – 5 Year Warrantees

Traditional Cobra Head Luminaire

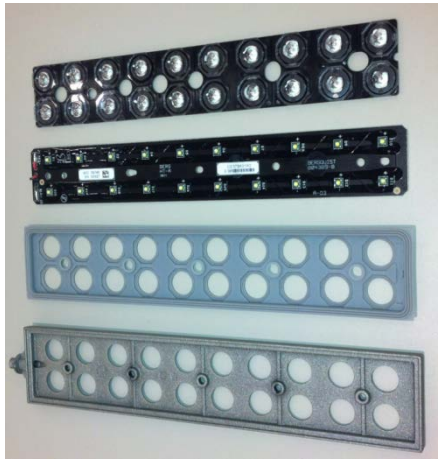
The Cost and Risk of Serviceability Features

- Removable Door (tool-less) With Serviceable Driver
- IP Rated Connectors



Serviceable and Upgradeable LED and Optics Array

- Mechanically Constrained
  - LED Package Choices
  - Optics



Industry Standard Twist-Lock Photo Control

Receptacle

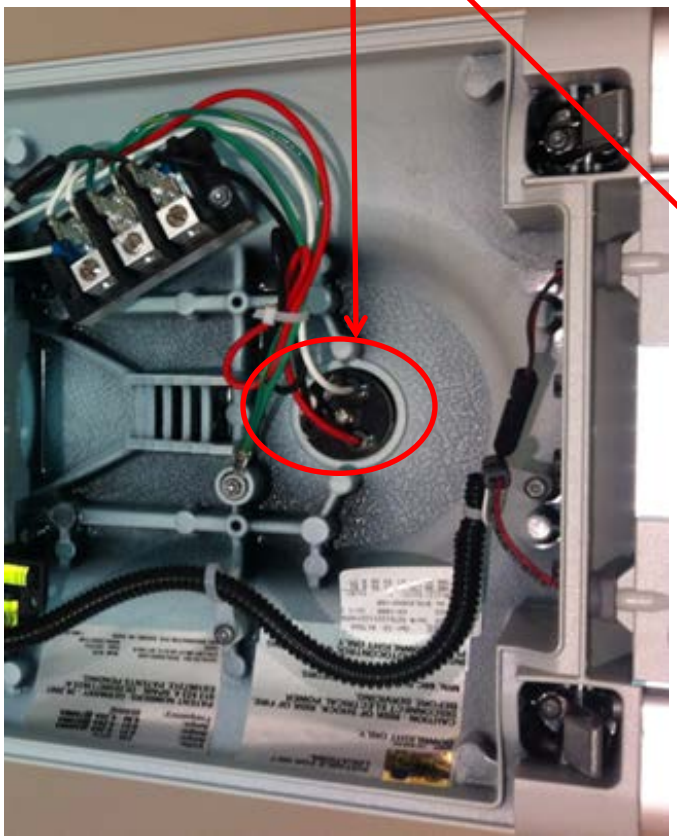


Photo control
(Weakest Link?)

Top View Position

BOM Cost Proportions 2008

- LEDs are Relatively Expensive ($/klm)
  - Relatively High Percentage of the Total Luminaire cost
- Viable Hi Power LED Packages Required Many Devices
- More Packages Allows for Greater “Fine Tuning” *(Advantage)*
  - More SKUs
    - Manufacturing Time and Inventory Management Challenges *(Disadvantage)*

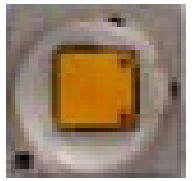
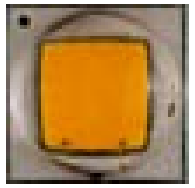
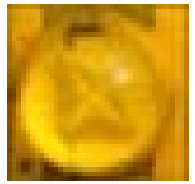
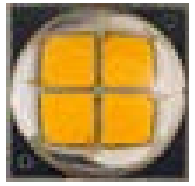
Evolving to Higher Value Solutions

Enabled by a Shift in User Expectations

- Reliability Concerns Lessen Over Time
  - Much Less Concern About the LED Components
  - Driver Reliability Still a Concern
- LEDs Are Better and Cheaper
  - For a Given Package Configuration:
    - More Light
    - Less Heat
    - Lower $/Lumen

Evolving to Higher Value Solutions

- New Chip Package Architectures
  - Smaller and Cooler Operating Chip Packages
  - Larger Chips in Smaller Packages
  - Multi Chip Packages
  - Specialty Packages
- Advancements in Optical Control Technologies and Manufacturing Processes
  - Significant Gains in Optical Performance
    - Optical Precision
    - Brightness Control


Evolving to Higher Value Solutions

- All Electrical Components Assembled to One Sub-component
- No Power Door
  - No Expensive Connectors
    - Higher Reliability
- Fewer and Higher Output Packages
- More Refined Optics
- Fewer Mechanical Parts
  - Overall Inventory Management Improvements
    - Costs, Lead Times, etc…
- Reduced Assembly Activity
  - Assembly Cost Reductions
  - More Robust Products

2012

Evolving to Higher Value Solutions

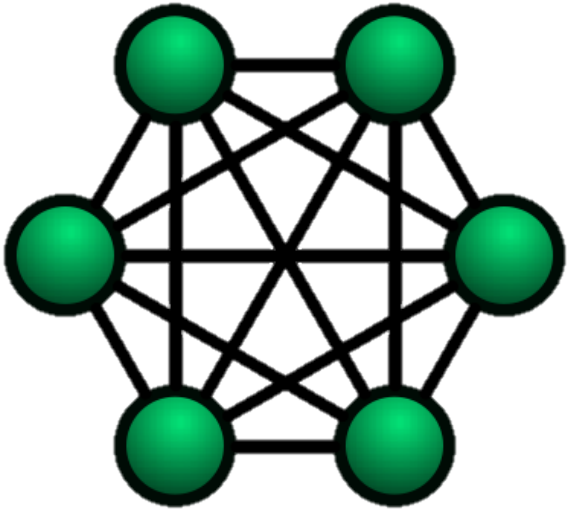
- Driver, LED Array, and Optics Serviceable/Upgradeable
  - Less Convenient to “Field Service”
- Twist Lock Photo Control
  - Less Reliable Than the Rest of the System
- Increased Demand for “Controls Ready Luminaires”
  - “Field Upgradable” to a Network Based System

2012

The Influence of Controls on Product Evolution

Lighting Control Technologies

- Network Based

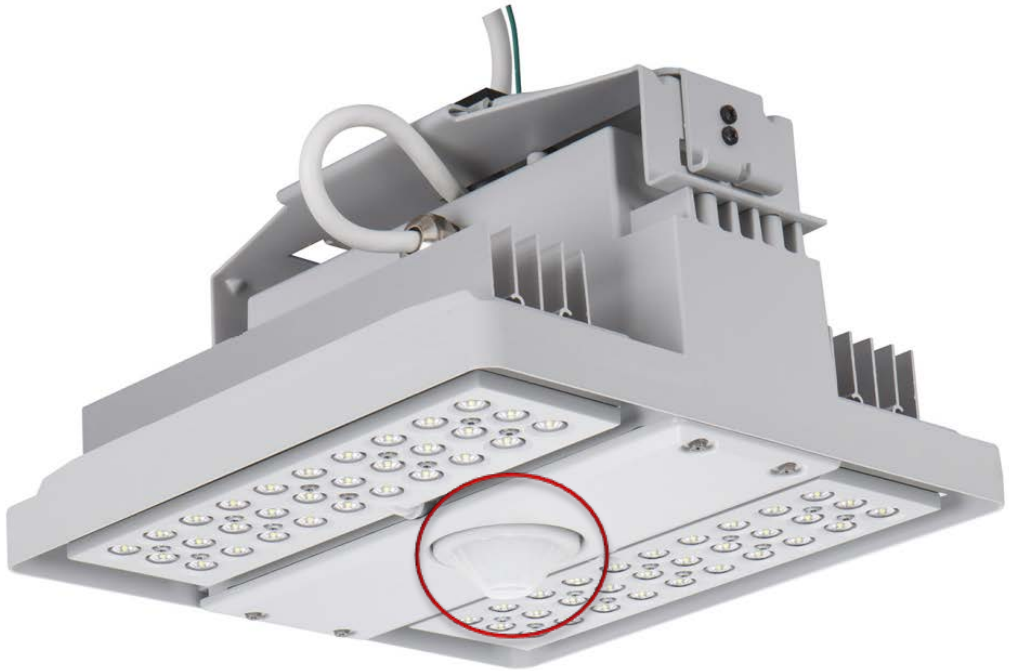


- Non-network Based
  - On-board Occupancy Sensors (for example)

Non-network Based Example

- On-board Occupancy Sensor

Area Lighting



Parking Structure

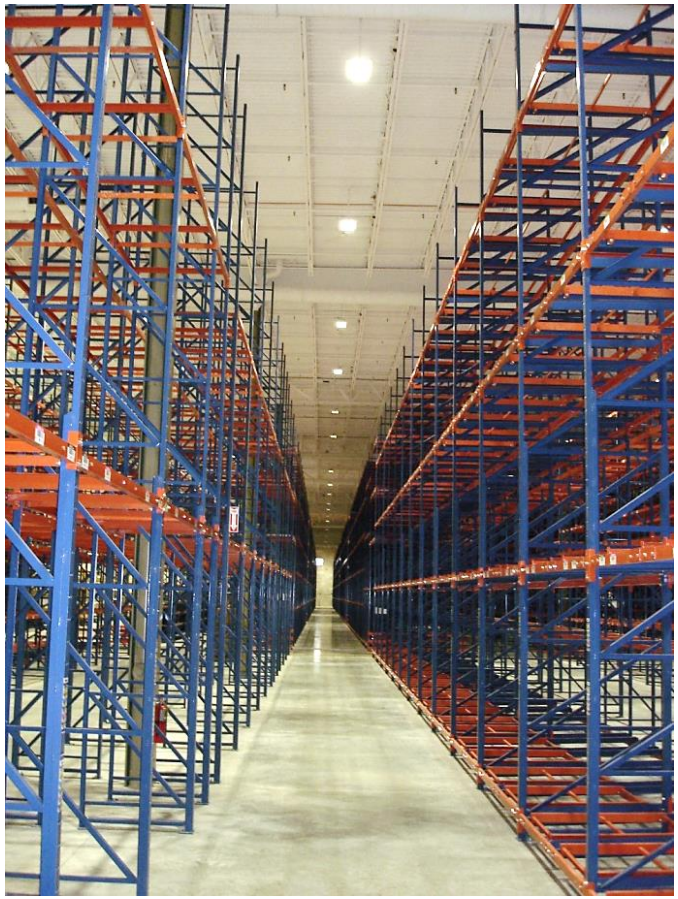
Non-network Based Solution Advantages

- Simple
- Reliable
- Sustainable
- Self Commissioning

Parking Structures

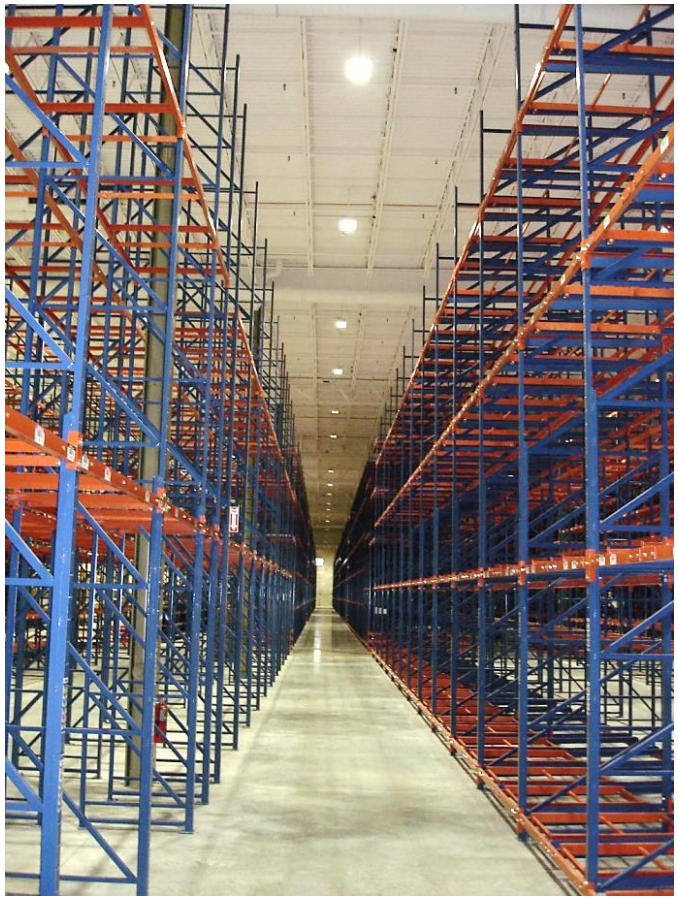
Parking Structure Occupancy

Warehouse Aisle Lighting



- Warehouse Occupancy Monitoring
  - Many are 24 x 7 operation
  - Low Average Occupancy per Square Foot
  - Simple (i.e. Non-Network Based) Adaptive Lighting Protocol Possibilities
    - Occupancy
    - Daylight Harvesting
    - Cumulative Energy Use Monitoring

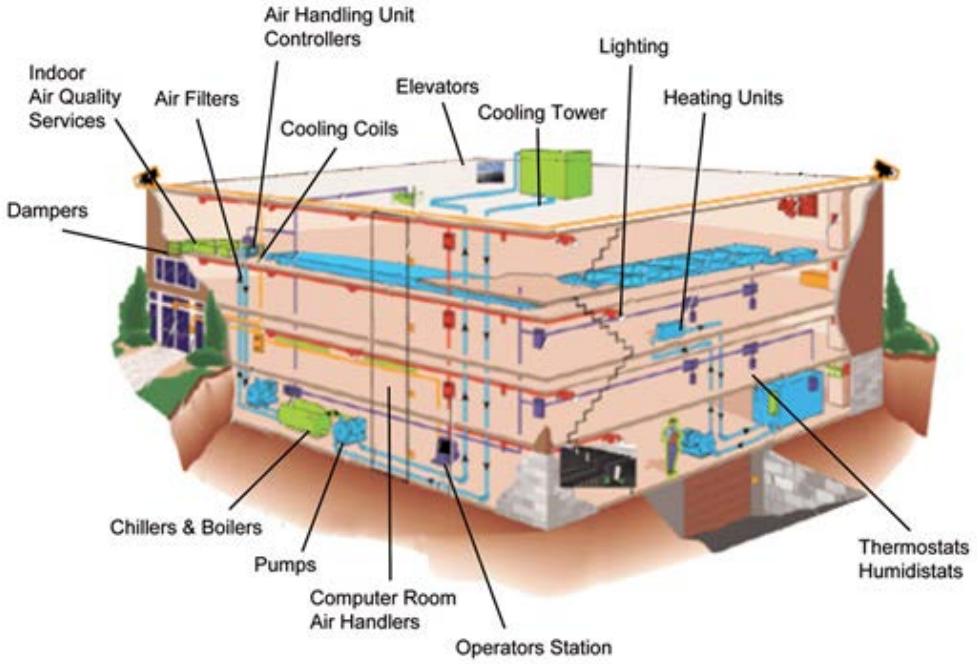
Other Occupancy Monitoring Uses???



- Activity Monitoring With Networking
  - Optimize Inventory Placement
    - Traffic Activity
      - Highest Pick to Ship Efficiencies
    - Traffic Mapping Histograms
      - Eliminate Traffic Conflicts
      - Integration With Inventory Management Systems

Commercial Space Environmental Monitoring and Control

- HVAC
  - Heating, Cooling Ventilation, Humidity
- Security
  - Access Control
  - Identify Threats
- Fire Protection
  - Detection
  - Suppression
- Lighting
  - Optimizing the Visual Environment



Monitoring and Connecting

- HVAC
  - Occupancy
  - Temperature, CO_2 etc.
- Security
  - Occupancy
- Fire Protection
  - Occupancy
  - Heat / Smoke / CO
- Lighting
  - Occupancy
  - Ambient Light

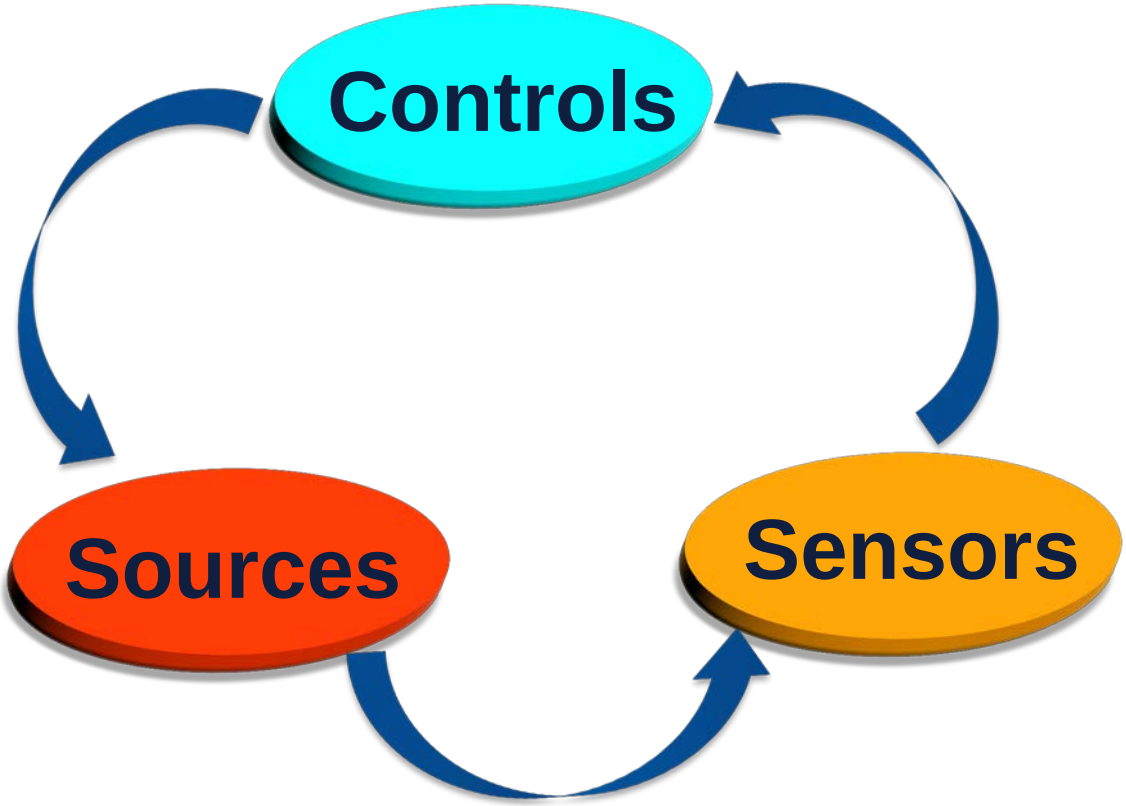
- First Meeting - 1987
- Standard (BACnet) Published - 1995
- Lighting Applications Added - 2001

Automation and Control Primary Goal?

Energy and Other Operation Cost Savings

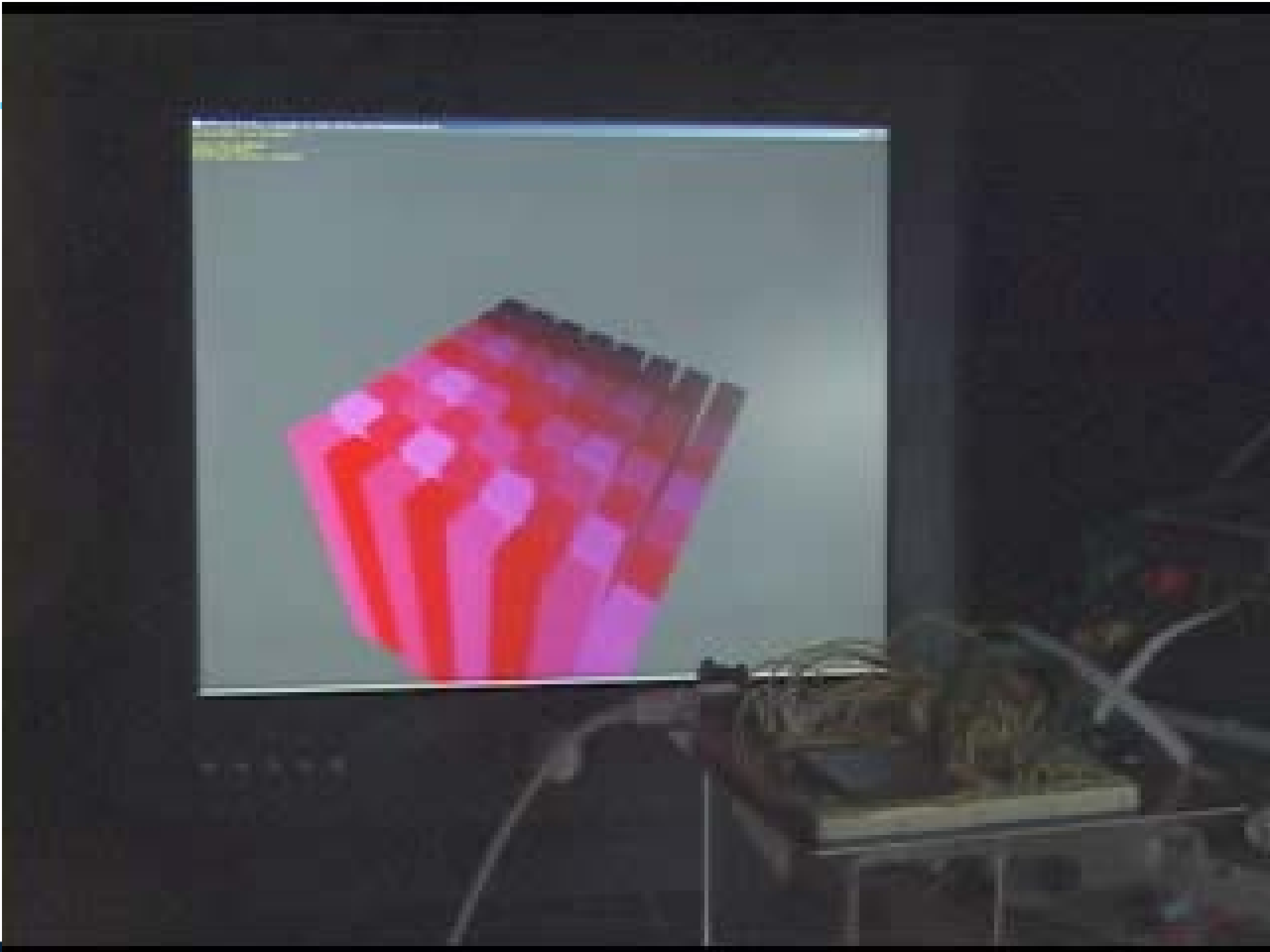
Environmental and Productivity Enhancement

Monitoring and Adaptation

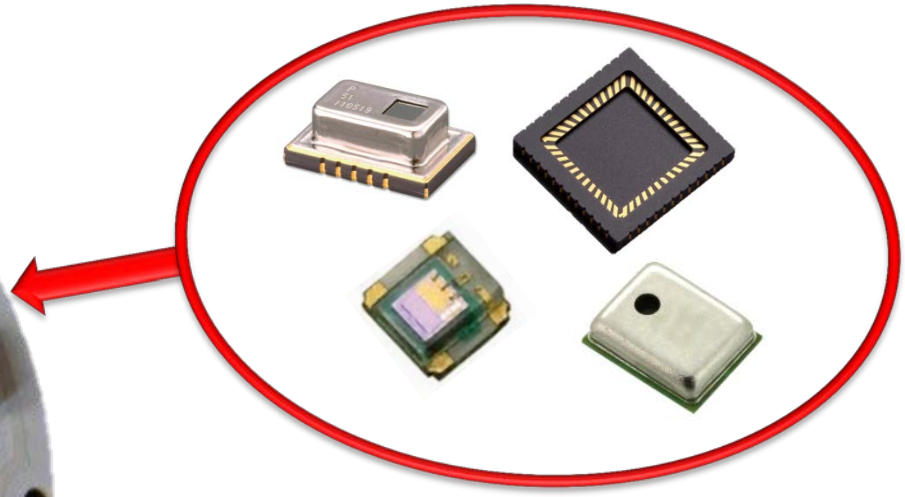


Sensors

- Types
- Placement
- Coverage
- Accuracy vs. Density
- Aesthetics
- Cost



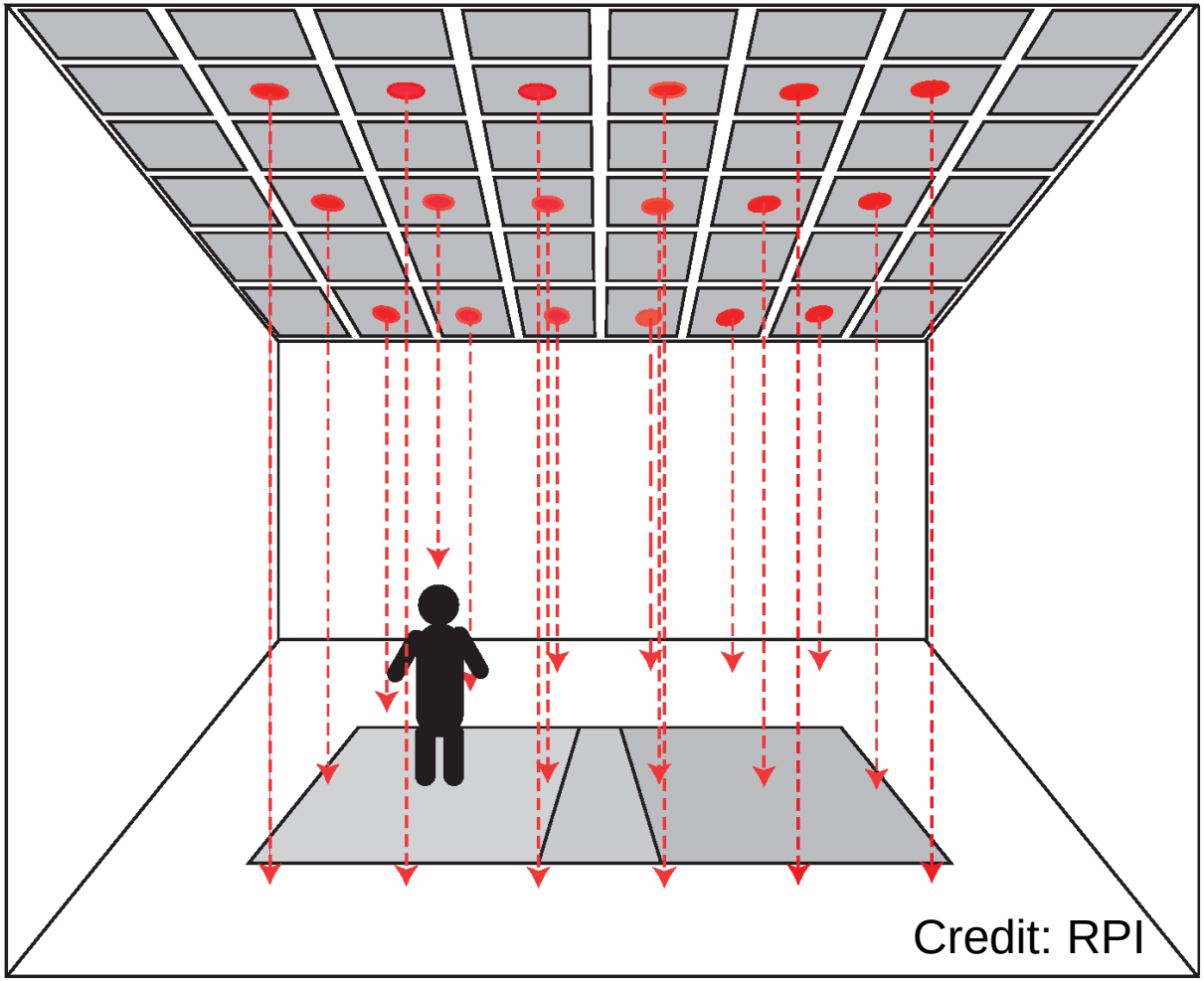
LED Array With Sensors



- Capable of Detecting
  - Heat
  - Light
  - Sound
  - Image

Luminaires That Act As Sensors?

- Occupancy
- Temperature
- Smoke/Haze
- Sound
- Daylight
- Man Made Light
- Etc…



Space Mapping Possibilities

Enables Better Collection and Distribution of Data

- Higher Sensor Density
  - Accuracy
  - Reliability
- Sensor Technology Redundancy
  - Space Condition Identification Accuracy
- Invisible
- Less Costly
  - Integrated into Existing LED Board
    - LEDs, PIR, Microphone, etc…

Facilities Use Monitoring / Optimization

- High $$$ per sq. ft. Areas
  - Auditoriums
  - Media Centers
  - Conference Room

- Example: Different Environmental Conditions Correlate to Different Types of Use
  - Used or not Used
  - Intended Use vs. Unintended Use
    - Histograms of Lighting Scene Settings
  - Occupancy Density?
  - Etc…

Expanded Security Functionality

- Alerts of Security Breaches
  - Illumination of Desired Areas
  - Flashing Luminaires to Identify Threat Location/Translation
  - Identify Safe Paths to Egress

Some Interesting Observations

- Luminaires are the typically most prevalent objects in commercial building spaces

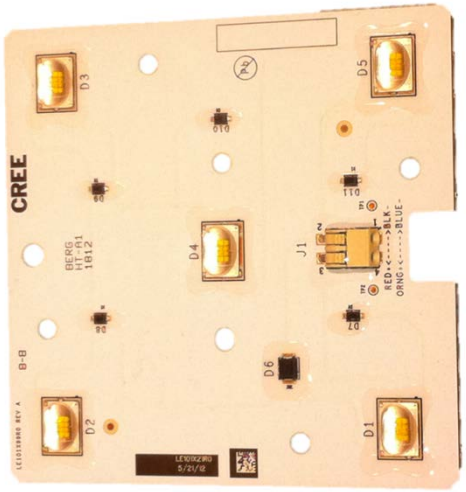
- LED luminaires can potentially improve building automation functionality
  - Consolidation of many building automation sensor and distribution functionalities into a more efficient configuration
  - Allows more information to be collected and distributed throughout the network for better environmental adaptation

What Will the Next Generation of Street Light Luminaires Look Like?

Street Light Luminaires

LED Driver

Packaged LED Chips

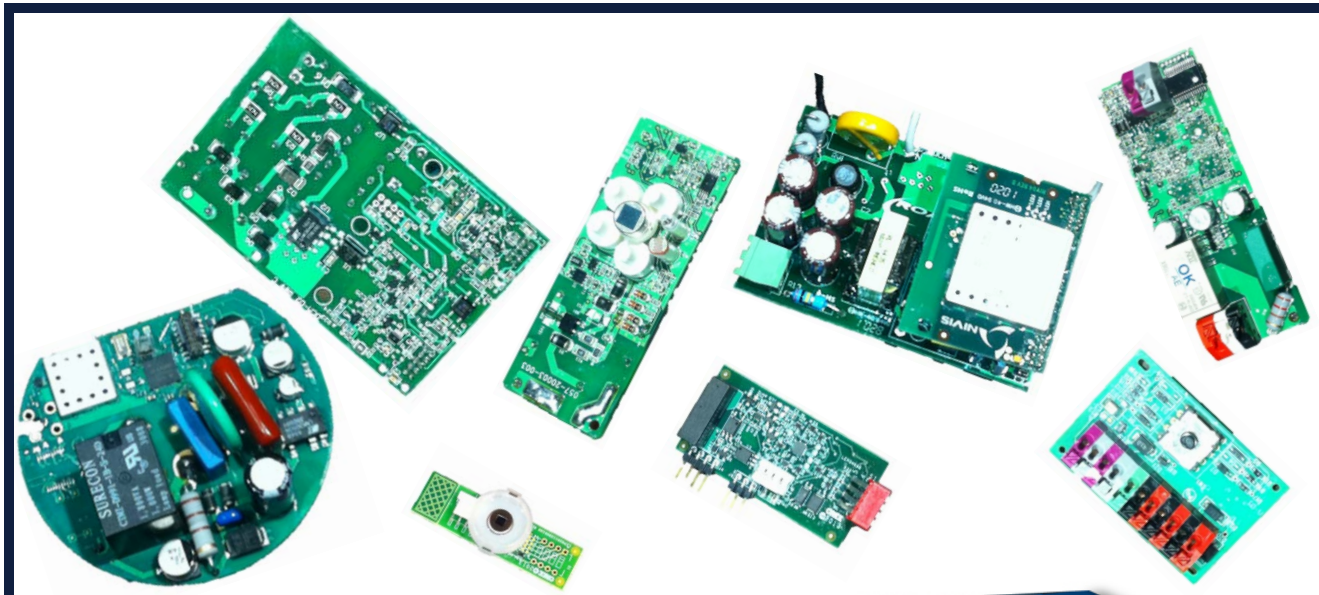


Daylight Sensing

0-10V Diming

Wireless Control

Occupancy Sensing



Component and Process Consolidation for Greater Overall Value

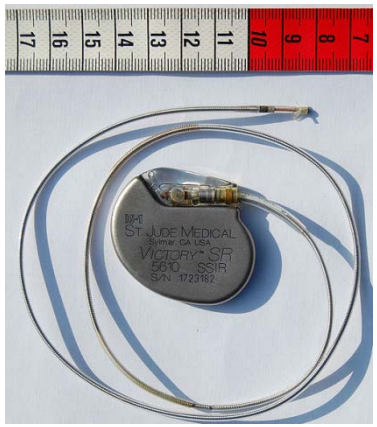
- **Fewer Electronic Components and Circuit Boards**
- **Fewer Manufacturing Process Steps and Associated Risk (Higher Reliability)**
- **Full Function Solutions With Flexibility to Configure/Reconfigure as Needed (programmable?)**
- **Higher Energy Performance Possibilities**
- **Less Electrical Compatibility Conflicts**
- **Lowest Average Product Cost**
- **Greater Possibilities for Highly Reliable Solutions**

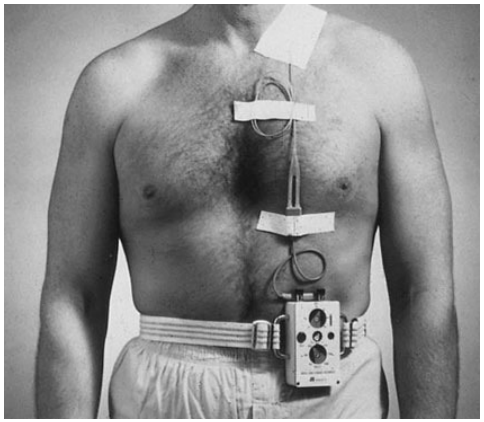
Do they need to be“serviceable”???

Do We Live in a World Where High Reliability Electronics Are a Assumed?

Engine Control Units (ECU) / Powertrain Control Units (PCM)

Heart Pacemakers





In 1958, Arne Larsson (1915–2001) became the first to receive an implantable pacemaker. He had a total of 26 devices during his life and campaigned for other patients needing pacemakers.

Overcoming Resistance to the “Non-Serviceable” Solution

- High Reliability
- Long Warranty Periods
- Acceptance of Non-traditional Form-factors
- Acceptance of Non-traditional Materials and Manufacturing Processes
- Standardization of Control System Functions (How Much?)
  - Software?
  - Hardware?
- Programmable Electronics
  - Luminaires Commissioned/Pre-commissioned at Factory
  - Control System Licensing/Contracts as Part of the Luminaire Specification and Purchasing Process
- Easily Salvageable NOT Serviceable

Is Adoption Accelerating?

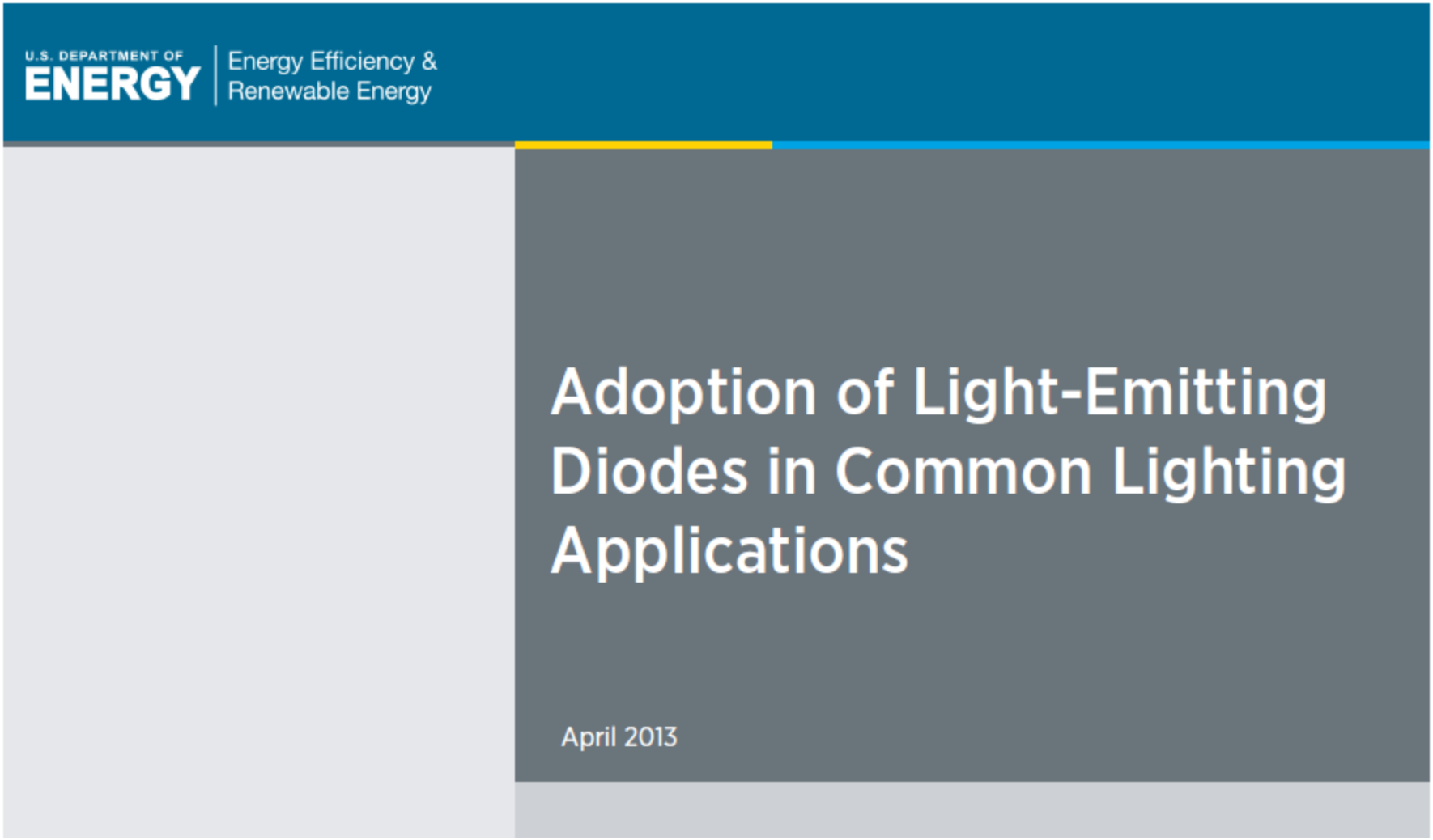
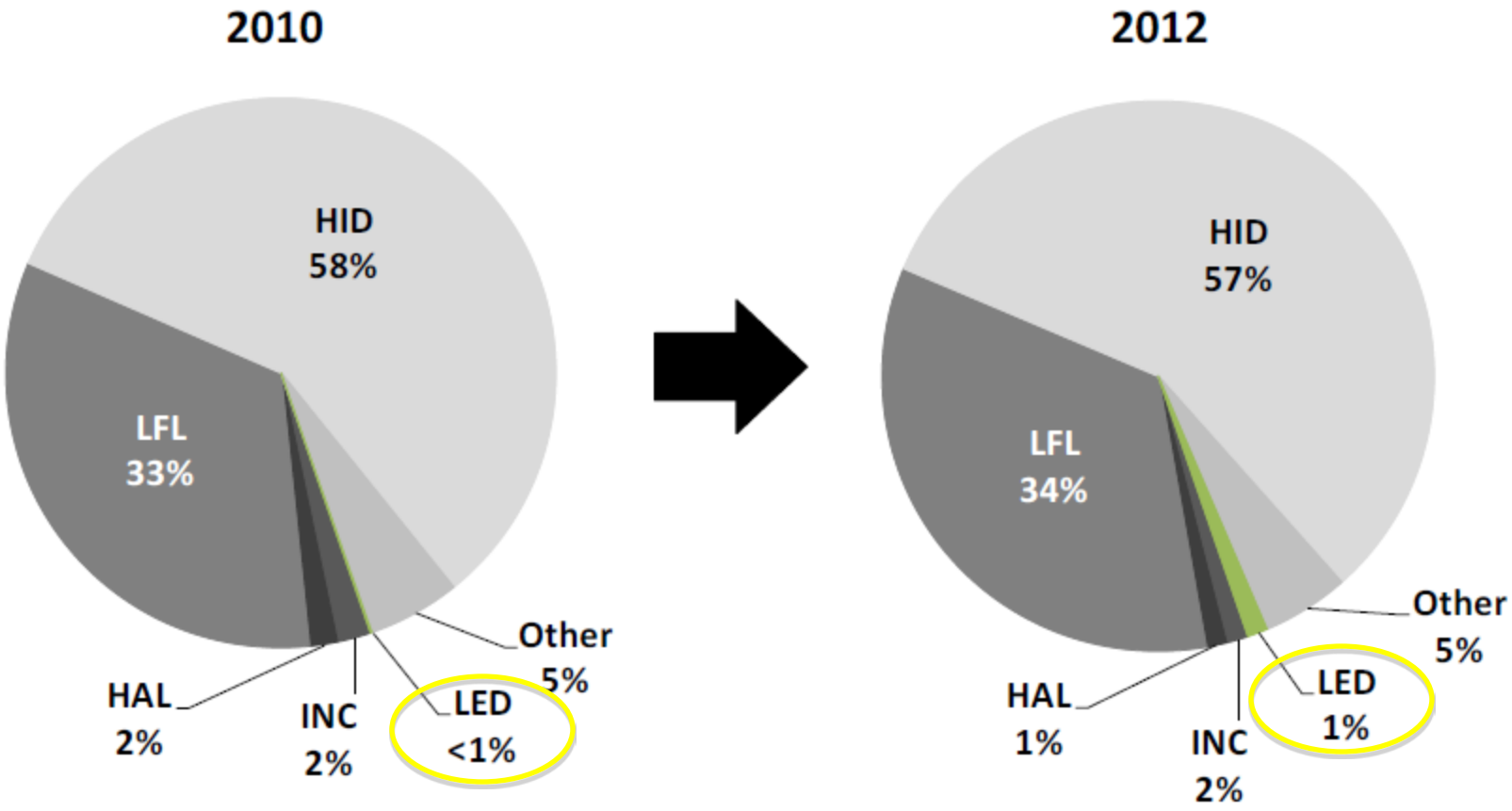
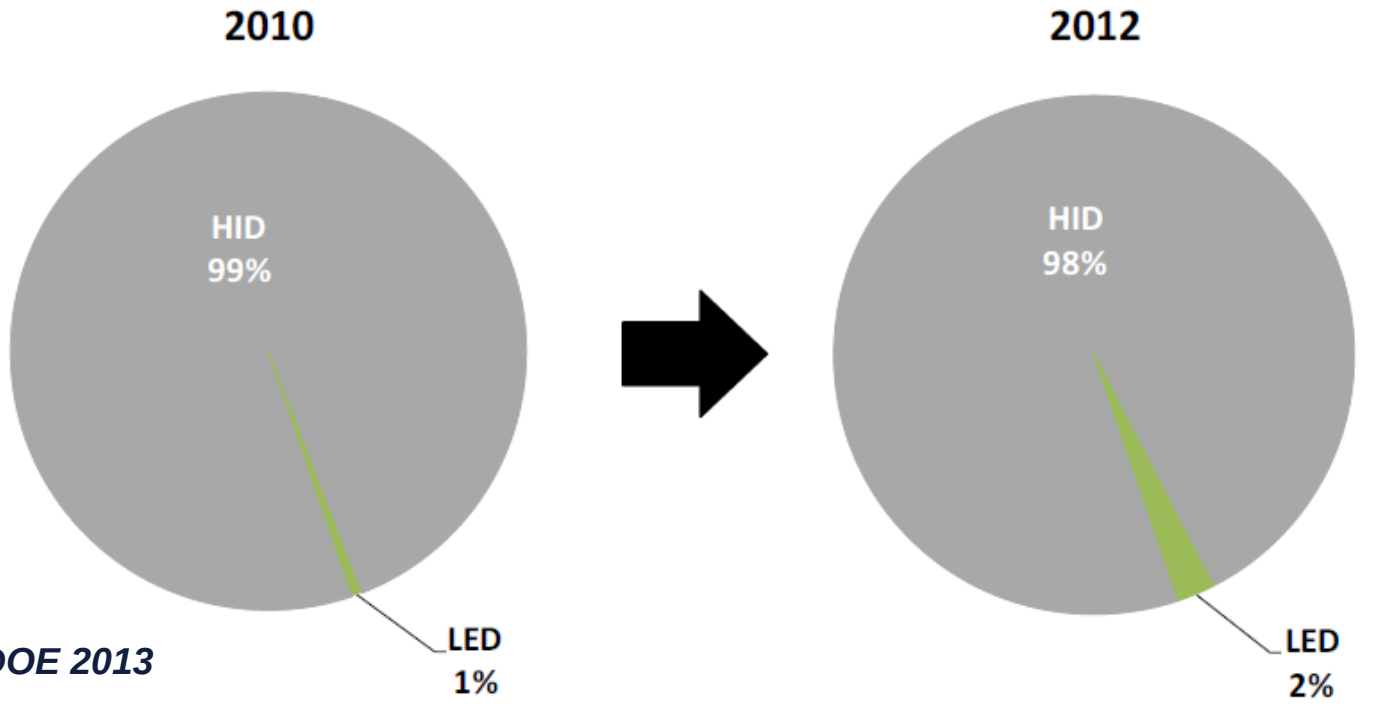


Figure 4.3 – Installed Base Estimates for LED Parking Luminaires[57]



*Values less than 0.1% are considered negligible

Figure 4.1 – Installed Base Estimates for LED Streetlight Luminaires[53,54]



DOE 2013

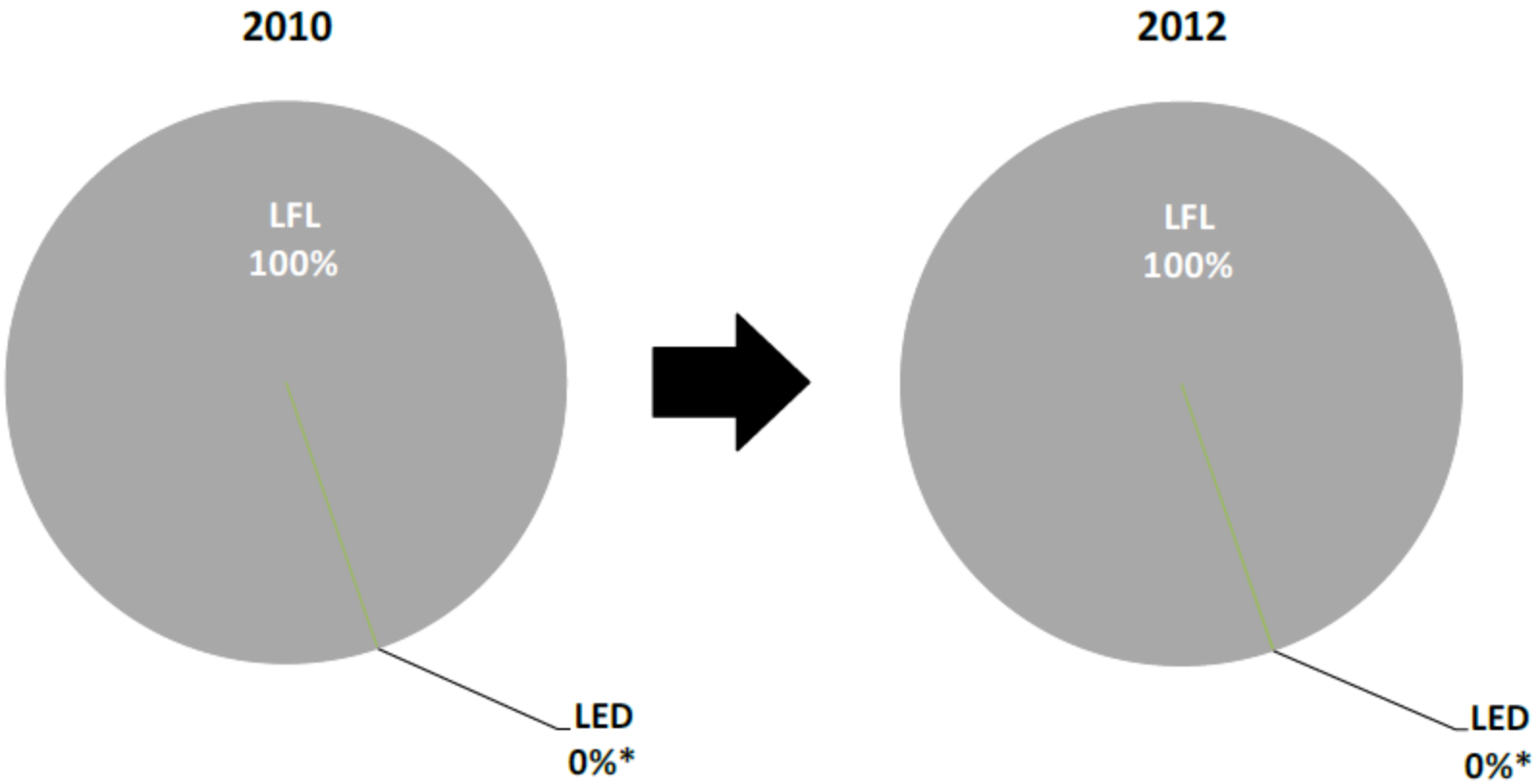
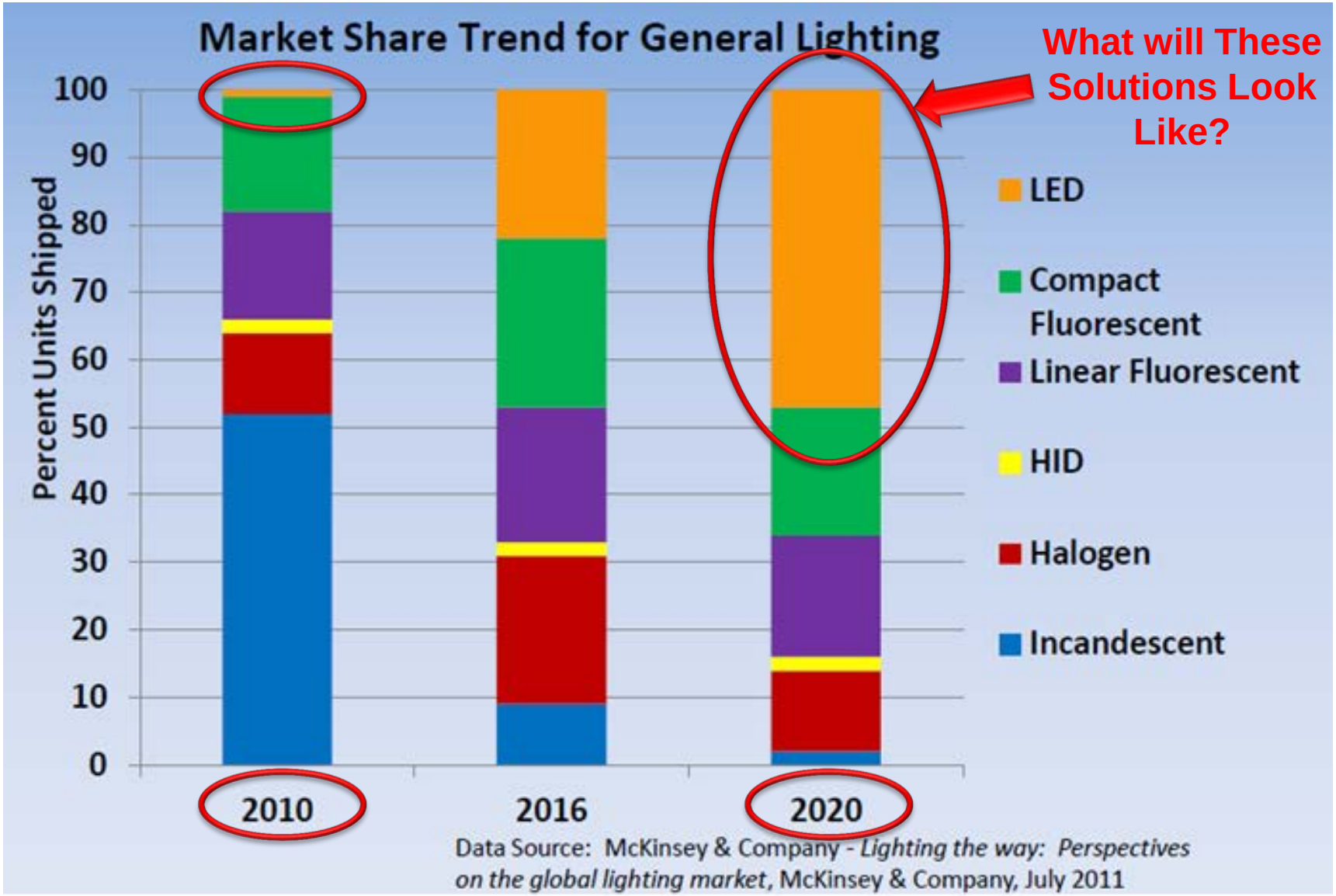
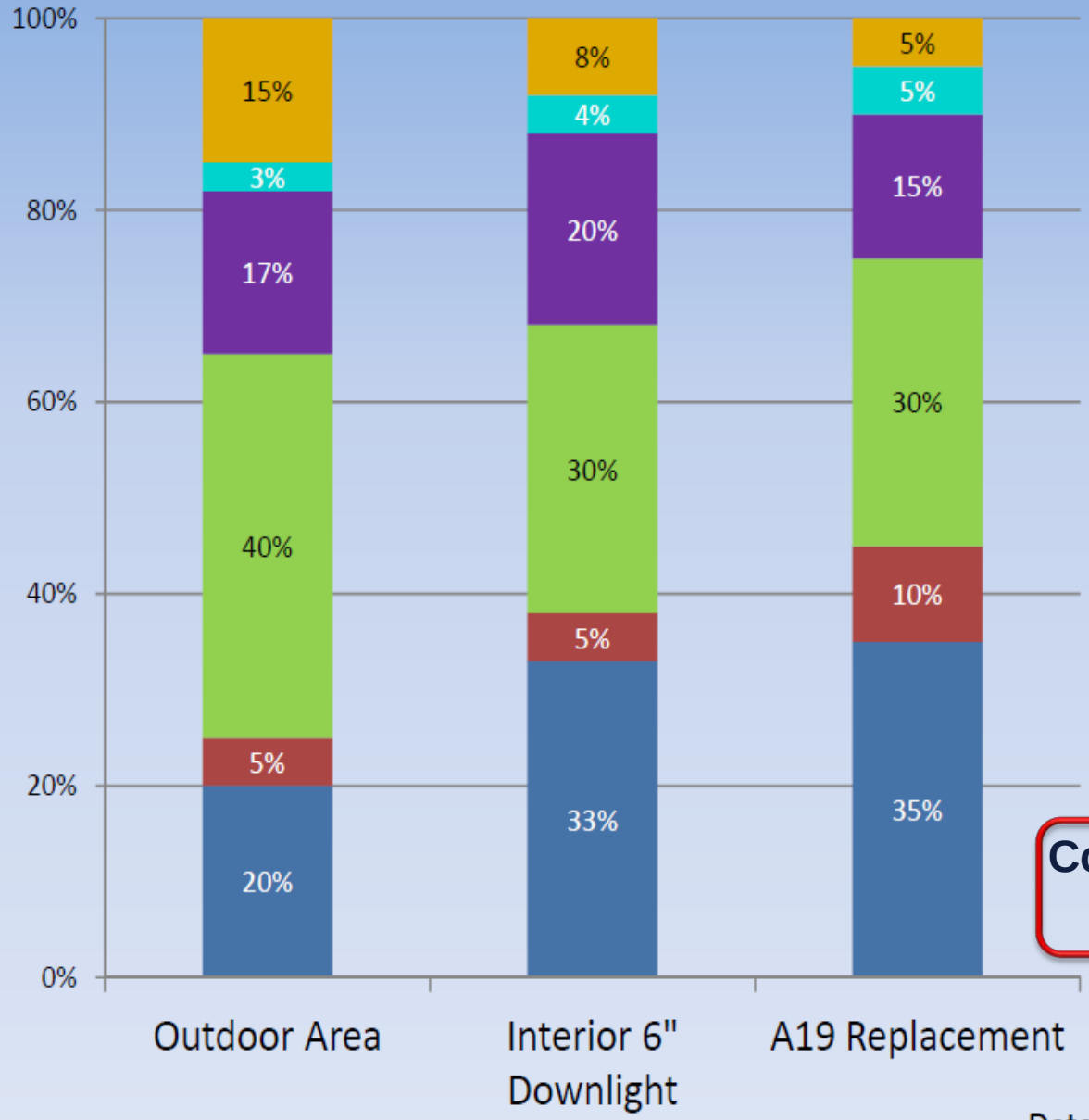


Figure 3.7 – Troffer and Other Common Fluorescent Fixture Installed Base

LED Adoption Estimates



Cost Breakdown for Various LED Solutions



We Need to Shrink All Remaining Costs

- Overhead
- Assembly
- Driver
- Mech/Thermal
- Optics
- LED Package

Cost Per Delivered Performance Continues to Shrink

Data source: DOE R&D Manufacturing Roadmap, September 2013

What Will the Products of the Future Look Like?

- New Form Factors
- Smaller Volumetrically / Lighter Weight
  - With Illumination Performance Improvements; Brightness Control, etc.
- Less LED Material at Higher Power???
- More LED Material at Lower Power???
  - Cheaper and Better LEDs
  - Less Heat…
- More Housing Material Options
  - Plastics… Low Environmental Impact Options
- As Close to One Highly Reliable Circuit Board as Possible
  - Fully Populated for all Possible Functionality (Less SKUs)
    - Programed at Factory or During Installation (Commissioning)
  - Populated as Needed (More SKUs, More Inventory Challenges)

Thank You!